Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 45 (2016) 195 – 198

www.elsevier.com/locate/procedia

3rd CIRP Conference on Surface Integrity (CIRP CSI)

Wet abrasive jet machining to prepare and design the cutting edge micro shape

Dirk Biermann[a], Robert Aßmuth[a]*, Sebastian Schumann[a], Michael Rieger[b], Bernd Kuhlenkötter[b]

[a]*Institute of Machining Technology, Technische Universität Dortmund, Baroper Straße 303, 44227 Dortmund, Germany*
[b]*Chair of Production Systems, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany*

* Corresponding author. Tel.: +49-231-755-2578; fax: +49-231-755-5141. *E-mail address:* assmuth@isf.de

Abstract

Cutting edge preparation is utilized to increase the stability of cutting tools and to improve the adhesion strength of a subsequent coating. In this context wet abrasive jet machining with a robot guided system allows to prepare local tool areas and to realize a specific design of the cutting edge, as well as advantageous surface qualities. This paper is concerned with the requirements and challenges in preparing and designing the cutting edge micro shape using wet abrasive jet machining. Important factors of the process as well as resultant shapes and topography effects of the machined cutting edges are discussed.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)

Keywords: Cutting edge; geometry; surface integrity

1. Motivation and investigation approach

The preparation of cutting tool edges has proven to be very important to increase the performance of cutting tools. In literature, there are a significant number of scientific investigations analyzing the performance of prepared tools. Depending on the machining process, the process parameters, the workpiece and cutting tool material, as well as the design of the cutting edge micro shape, relating phenomena may vary [1,2,3]. In particular, the design of the cutting edge micro shape is of crucial importance for the performance of the coated cutting tool.

The micro shape and size of the prepared cutting edge represent two significant factors for the tool performance. Often a rounded shape of the cutting edge is produced, since its advantage is to affect a smoothening of micro defects along the ground surface transitions. Nevertheless, a rounded transition does not have to look like a circle so that an inclination of the transition point, towards the rake or flank face, is often defined to enhance the performance of the tool [1,4]. Besides the determination of a suitable design, one of the main challenges in this field is the reproducible realization of the micro shape at the tools' cutting edges. Content of this paper are investigations of wet abrasive jet machining as a promising and sophisticated technology for preparing cutting edge micro shapes. In particular, the handling parameters influencing the micro shape and size of the cutting edge when using a robot-guided system are analyzed.

Nomenclature

$\alpha_{jet,rel}$	relative jet inclination angle
β	wedge angle
h_d	jet nozzle distance
K	form-factor
S_γ	cutting edge segment on rake face
S_α	cutting edge segment on flank face
$\overline{S}$	average cutting edge rounding
$v_{f,jet}$	jet feed speed
R^2_{adj}	adjusted r-squared

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)
doi:10.1016/j.procir.2016.02.071

1.1. Wet abrasive jet machining with robot-guided systems

For cutting edge preparation wet abrasive jet machining offers a number of benefits. Investigations show that residual compressive stresses are induced in the blasted workpiece areas [5,6]. If using a robot to guide the cutting tool, the possibility to prepare cutting edges with a complex shape and of focusing locally restricted tool and edge areas need to be emphasized, too. Due to that the configuration of asymmetric micro roundings is feasible by applying this method.

Compared to dry blasting processes, further advantages can be achieved by the usage of water and abrasive suspension. Water has a damping effect which is important for the smoothening of the machined surfaces [5,7] and, in addition, helps to prevent powder accumulation [7]. Further, due to its conducting properties, thermal damages can be reduced or avoided if preparing with wet abrasive jet machining [8].

The major challenge in wet abrasive jet machining with a robot-guided systems is the complexity of process execution. In these processes, the setting of the cutting edge micro shape is attributable to a large number of interacting and influencing variables, which primarily include the jet delivery, the workpiece parameters and the cutting edge handling. The jet delivery comprises among others the jet parameters e.g. the specification of abrasive medium, the jet mass concentration, the jet pressures, the jet distribution intensity, the nozzle outlet diameter and the jet expansion angle. The workpiece parameters encompass the workpiece material specifications, the wedge angle and the initial shape of the edge [9]. The cutting edge handling parameters are discussed with in the following chapter.

1.2. Experimental setup

This work investigates the influence of cutting edge handling parameters if applying wet abrasive jet machining. Due to intended subsequent applications, such as the preparation of cutting tools with complex shaped cutting edges, as well as the accessibility of the respective cutting edges, the motion control is conducted by use of an industrial robot, shown in Figure 1. For the evaluation of the handling parameters the current workpieces are ground cemented carbide rods with five different wedge angles ($\beta = 38°$; 45°; 62.5°; 80°; 87°).

Fig. 1. (a) Wet abrasive jet machining with industrial robot; (b) cutting edge handling parameters for the robot guidance.

The cemented carbide consists of 13% cobalt and 87% tungsten carbide with a particle size of less than 0.5 µm. The workpiece is led along the cutting edge horizontally aligned under the incident jet. As schematically shown the jet feed speed $v_{f,jet}$, the jet nozzle distance h_d and the relative jet inclination angle $\alpha_{jet,rel}$ are varied. The relative jet inclination angle refers to the wedge angle's bisector crosswise to the edge. Together with the variation of the wedge angle, the findings are based on 320 experimental combinations.

The jet parameters are not varied. The jet medium is a suspension of water and abrasive material with a jet mass concentration of $\gamma_{st} \approx 10\%$. The abrasive material is new and sharp-edged aluminum oxide with a size of FEPA 220. Using a jet nozzle with an outlet diameter of $d_d = 4.5$ mm, the jet pressure at the nozzle outlet is at $p_{st} \approx 3.2$ bar.

1.3. Characteristic values of cutting edge micro shape

There are two methods that are commonly applied for measuring the size of rounded shaped cutting edges using profile sections. One is to describe the rounding size of the edge by fitting its profile sections with a circle, resulting in the cutting edge radius r_β. However, using this approach, an inclination of the profile cannot be considered. Thus there is a risk of oversimplifying the edge micro shape [7]. An alternative approach is to measure the length of the profile sections with respect to the take-off points from the rake face (S_γ) and the flank face side (S_α) towards the tip of the ideal sharp cutting edge. Both lengths are summarized by their average value to the average cutting edge rounding $\bar{S}$. The ratio of the segment on the rake face side to the flank face side results in the form-factor K, specifying the orientation of the rounding [1]. In general, a large number of profile sections are considered in both approaches to calculate average values. Values further depend on user-specified settings affecting the fitting and take-off points.

In this work $\bar{S}$ and K are utilized. Each target value has been derived from 100 profile sections, evaluated over a measuring length of 0.6 mm with the help of a digital fringe projection microscope. An illustration of measuring S_γ and S_α is shown by example of a wedge angle of $\beta = 62.5°$ in Figure 2 (a). The two other illustrations of wedge angles with $\beta = 45°$ and $\beta = 80°$ give an idea of how the wedge angle sizes affect the initial and prepared condition of cutting edges.

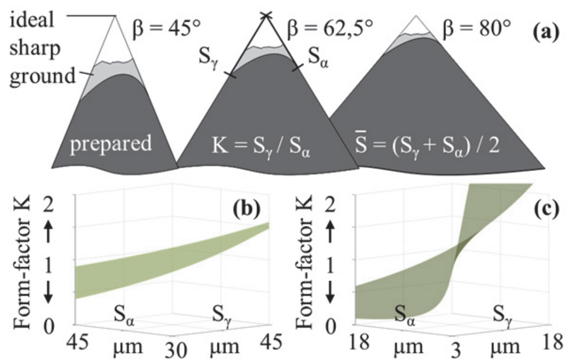

Fig. 2. (a) Cutting edge characterization; (b) achievable form-factors for $\bar{S} = 30 \ldots 45$ µm; (c) achievable form-factors for $\bar{S} = 3 \ldots 18$ µm.

In general, ground cutting edges at big wedge angles are sharp since they have fewer breakouts in the tip area. Smaller wedge angles have less material support in the tip area, thus exhibiting larger micro defects after grinding. Further, cutting edge preparation has a larger effect on the material removal at small wedge angles.

In addition, the diagrams (b) and (c) show the achievable form-factors in dependence of the material removal at the respective cutting edge segment. In this context, it is important to note that the form-factor is strongly influenced by the rounding size. As shown in the left diagram (b) in a range of $\overline{S} = 30 \ldots 45$ µm the alteration of the form-factor is dominantly influenced in terms of high deviations between S_γ and S_α. With regard to $\overline{S} \leq 18$ µm, resulting form-factors rapidly diverge from a uniform rounding with $K = 1$ as the gradient of the curve in the second diagram shows (c).

2. Wet abrasive jet machining of cutting edges

In the applied wet abrasive jet machining device, the pressurized water, serving as the carrier medium, gets accelerated through the jet nozzle. The delivery of the abrasive medium is based on the injection principle. In Figure 3, SEM-pictures of a ground (a) and a blasted (b) edge, also depicted with their cross-sectional profiles, are shown. The ground edge shows a sharp transition of the faces, exhibiting chipping and micro defects along the edge. Further, the grindings marks are recognizable. The blasted edge shows a rounded transition with fewer micro defects. Minor hole-like imperfections can be attributed to the release of carbide by removing the binder material through jet impact. Nevertheless, the surface is smoothed in comparison to the ground one, presenting the typical dimple structure after wet abrasive jet machining.

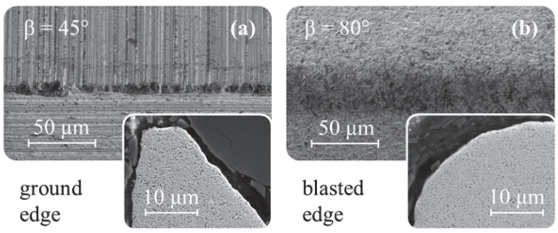

Fig. 3. (a) Ground cutting edge; (b) blasted cutting edge.

2.1. Adjusting average cutting edge rounding

Figure 4 shows the influence of $v_{f,jet}$ and h_d on the average cutting edge rounding $\overline{S}$ with respect to the wedge angles $\beta = 45°$, $\beta = 62.5°$ and $\beta = 80°$, if $\alpha_{jet,rel} = 0°$ is applied. It is obvious that the jet feed speed has a significant influence on the resulting rounding $\overline{S}$. The impact duration of the jet is defined by the jet feed speed. Slower jet feed speeds lead to an increase in material removal, while faster jet feed speeds result in a decrease in rounding size. In the case of the latter, compared to the original state of the cutting edge, only minor defects along the surface transition get removed. Thus, the diagram gives an idea about how ground edges can be characterized by means of the material removal values related to the ideal tip. It is clear that ground cutting edge micro shapes of big wedge angles are not as removed as smaller ones related to the ideal tip (also see Figure 2 (a)). The supporting effect of the surrounding material is reflected by the grinding as well as by the jet machining of the cutting edge. Subsequently, a stronger increase in rounding size by means of jet machining is given at smaller wedge angles.

Compared with the impact of β and $v_{f,jet}$ the influence of h_d in the range of $h_d = 5 \ldots 20$ mm is negligible concerning the rounding $\overline{S}$. Only slightly more material removal is achieved with the largest jet nozzle distance. It is likely, that at $h_d = 20$ mm, the maximum jet speed is achieved, resulting in a high impact intensity.

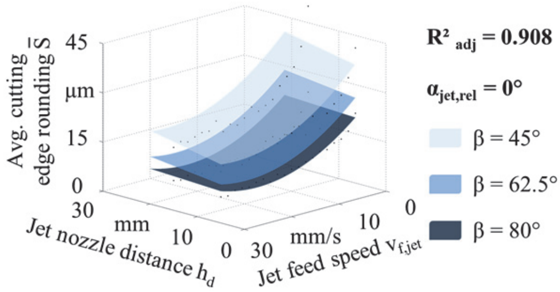

Fig. 4. Influence of jet nozzle distance and jet feed speed on the average cutting edge rounding.

Further influence on the rounding $\overline{S}$ is given by the relative jet inclination angle $\alpha_{jet,rel}$. In Figure 5, a maximum in material removal is discernable at around $\alpha_{jet,rel} = 0°$. Any inclination of the specimen leads away from a uniform distribution of the jet over the edge related to the flank and rake face side. A tilt of the edge changes the relative jet inclination angle. Therefore, the jet more strongly affects the adjacent flat surface areas. This results in a reduced material removal, which can be explained by the surrounding material support. With respect to the functional relationships shown in the diagrams in Figures 4 and 5, the value of adjusted r-square R^2_{adj} proves the reliability of the generated models. The maximum in average cutting edge rounding with $\overline{S} = 54.8$ µm is achieved at a wedge angle of $\beta = 38°$, applying $v_{f,jet} = 1{,}5$ mm/s, $h_d = 20$ mm and $\alpha_{jet,rel} = 0°$.

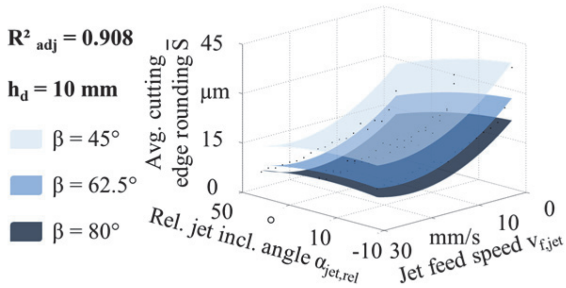

Fig. 5. Influence of relative jet inclination angle and jet feed speed on the average cutting edge rounding.

2.2. Adjusting form-factor

The form-factor is an extremely sensitive value since it is described by the ratio of material removal from the ideal tip to flank face and the rake face side. The condition of cutting edges and, moreover, linked with that the consideration of the respective wedge angles, are very essential in this context. As seen in Figure 2, minor deviations in S_γ and S_α at tools with bigger wedge angles lead to significantly different form-factors, if compared to cutting edges with smaller wedge angles. This is related to the respective size of the cutting edge rounding. Smaller roundings cause considerable changes in the resulting form-factor even for only minor deviations of the respective face-related material removal. With an increase in rounding, a higher deviation in face-related material removal is required to retain or alter the form-factor.

As shown in Figure 6, strong differences in the form-factor for each wedge angle at high jet feed speeds as well as the trend of the curves regarding lower $v_{f,st}$ can be explained. If applying high jet feed speeds, resulting in shorter impact duration, the initial condition of the edge changes only slightly. Considering the smaller backset of the ideal tip at the big wedge angle of β = 80, small S_γ and S_α strongly determine higher form-factors, as discussed above. Preparing the edges with $\alpha_{st,rel} = 0°$ leads to a uniform material removal related to the rake face and the flank face side. The average cutting edge rounding increases, hence the mentioned ratio for the form-factor converges to K = 1. Smaller deviations, visible in the diagram, can be caused by the initial condition of the cutting edge micro shape. Taking this into account, it is not possible to identify a clear influence of h_d.

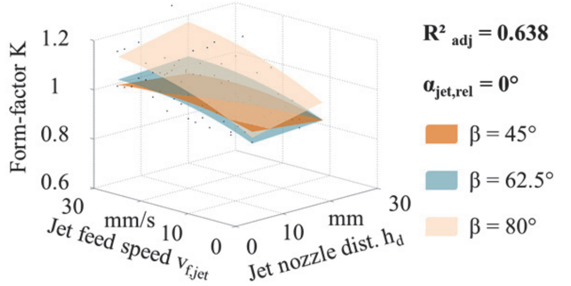

Fig.6. Influence of jet feed speed and jet nozzle distance on the form-factor.

In contrast $\alpha_{st,rel}$ has a strong impact on the resulting K. If by an inclination of the cutting edge the jet is primarily machining the flank face side, K will decrease. This is the case for positive relative jet inclination angles, illustrated in Figure 7.

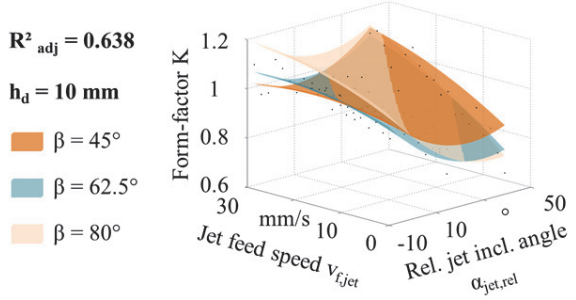

Fig.7. Influence of jet feed speed and rel. jet incl. angle on the form-factor.

If the specimen is not inclined with regard to its wedge angle bisector, K tends towards K = 1. In these cases K is equivalent to the minimum of each curve since ground conditions of the cutting edge of the specimens typically exhibited K ≥ 1. A stronger decrease of the form-factor at bigger wedge angles is related to smaller average cutting edge roundings. With respect to the impact of $v_{f,st}$, the form-factor also undergoes a major change, if the jet operates with a longer duration.

3. Conclusion and outlook

The results reveal that by means of water jet abrasive machining with robot-guided systems cutting edge preparation is feasible in a wide range regarding the examined characteristic values. With respect to the cutting edge handling parameters, it has been ascertained that the jet feed speed and the relative jet inclination angle have a strong influence on the resulting average cutting edge rounding and the form-factor. Further, it is shown that for a targeted preparation it is of significant importance to take the wedge angle of the tools and their initial cutting edge condition into account. In this context, it is essential to consider the relation between the form-factor and the rounding size when designing the cutting edge micro shape.

In order to evaluate the sensitivity and reproducibility of wet abrasive jet machining with a robot guided system, future investigations will consider varying jet parameters and workpiece specifications. The specific findings will then be transferred to real cutting tools.

Acknowledgements

This study is part of the research project “Automatisierung des Strahlspanprozesses zur Präparation von Werkzeug-schneidkanten - AutoEdge” that is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) within the framework of the ZIM program supported by the AiF. The authors are grateful to Arno Friedrichs Hartmetall GmbH & Co. KG for its support with cemented carbide specimens and to the project partners from carat robotic innovation GmbH.

References

[1] Denkena, B.; Biermann, D.: Cutting edge geometries. CIRP Annals – Manufacturing Technology 63 2014, p.631-653.

[2] Bouzakis KD, Bouzakis E, Kombogiannis S, Makrimallakis S, Skordaris G, Michailidis N, et al. Effect of Cutting Edge Preparation of Coated Tools on Their Performance in Milling Various Materials. CIRP Journal of Manufacturing Science and Technology 2014; 7:264-273.

[3] Rehe M. Herleitung prozessbezogener Kenngrößen der Schneidkantenverrundung im Fräsprozess, PhD Thesis, Leibniz Universität Hannover, PHZ Verlag, Garbsen, 2015.

[4] Bassett E. Belastungsspezifische Auslegung und Herstellung von Schneidkanten für Drehwerkzeuge, PhD Thesis, Leibniz Universität, PHZ Verlag, Garbsen, 2014.

[5] Terwey I. Steigerung der Leistungsfähigkeit von Vollhartmetallwendel-bohrern durch Strahlspanen, PhD Thesis, Technische Universität Dortmund, Vulkan Verlag, Essen, 2011.

[6] Tönshoff HK, Mohlfeld A. Surface Treatment of Cutting Tool Substrates. Int. Journal of Machine Tools and Manufacture 38 (5-6) 1998, p.469-476.

[7] Wyen C.-F. Rounded Cutting Edges and Their Influence in Machining Titanium, PhD-Thesis, ETH Zürich, Zürich, 2011.

[8] Saunders D. Jet Cutting Technology – Chapter 7: A Study of Brittle Erosion Mechanism Applied to Abrasive Waterjet Processes. Proceedings of the 10th Int. symposium Elsevier Science Publisher Ltd., Amsterdam, Netherlands, 1991.

[9] Rieger M, Aßmuth R, Biermann D, Kuhlenkötter B. Roboterbasiertes Strahlspanen zur Schneidkantenpräparation. Tagungsband VDE Mecha-tronik, 2015, p.7-12.